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(54) **Method and apparatus for scanning an object field from a movable carrier**

(57) The apparatus comprises an optical system having at least one objective lens (O) for providing an image of the object field or a part thereof and an array of photosensitive detectors (E) disposed in the image plane (IP) of the objective lens in at least one curved line, which may be for example an arc of a circle or a full circle, for detecting at least a part of the image, the apparatus being movable in a direction parallel to the image plane of the objection lens (O). A particular application is that of aerial infra-red terrain scanning, the detectors may be arranged in concentric circles or arcs and a stereoscopic image may be enabled by using two array systems spaced in the direction of aircraft movement. The outputs of the arrays may be stored for analysis.

FIG.1

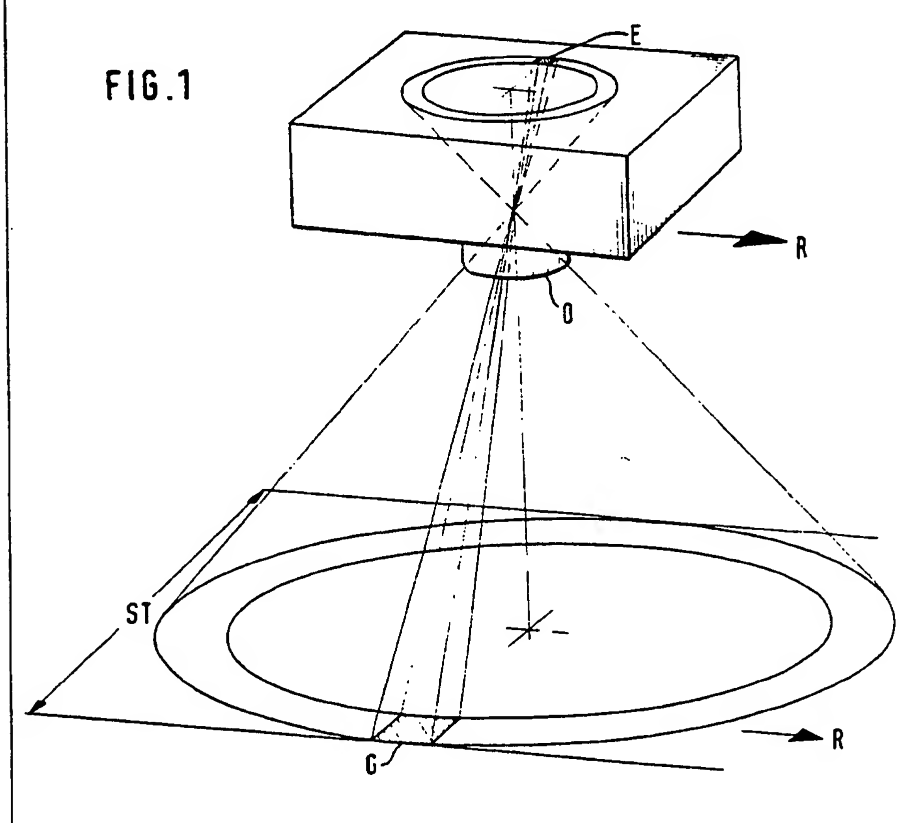

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FIG.1

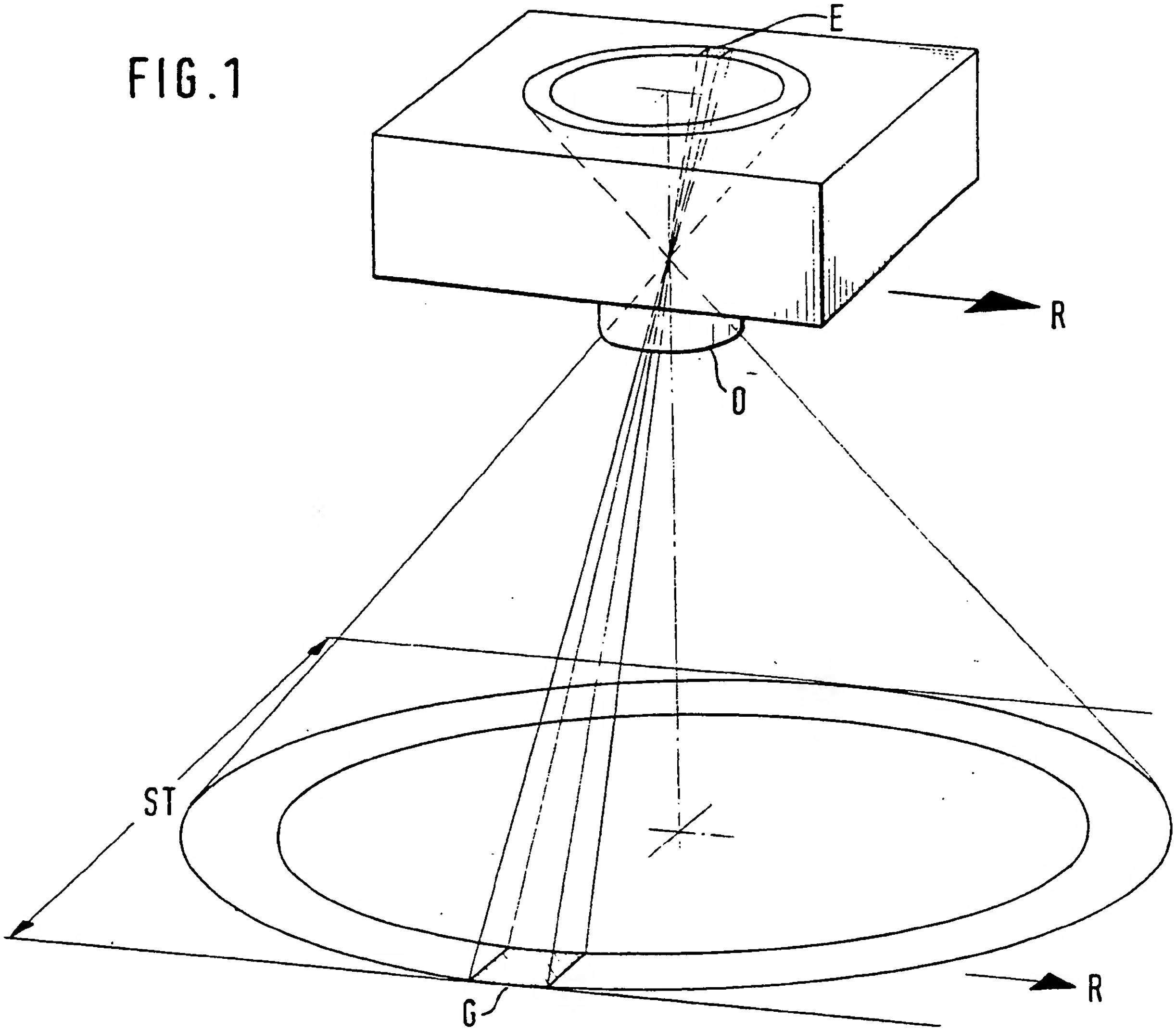


FIG.2

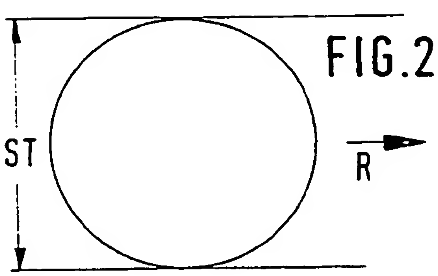
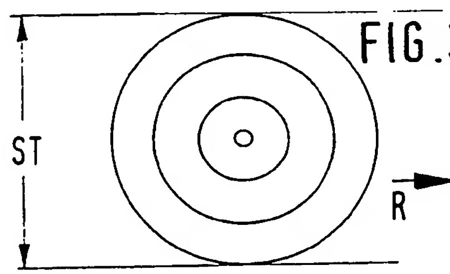


FIG.3



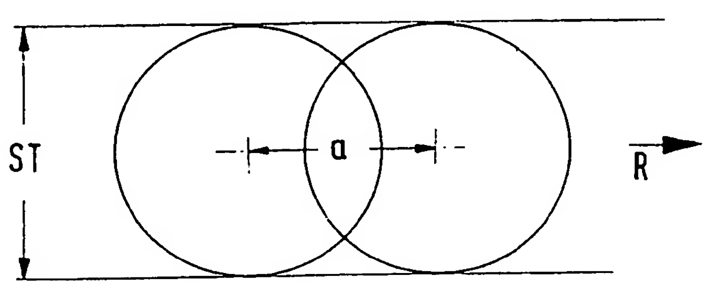
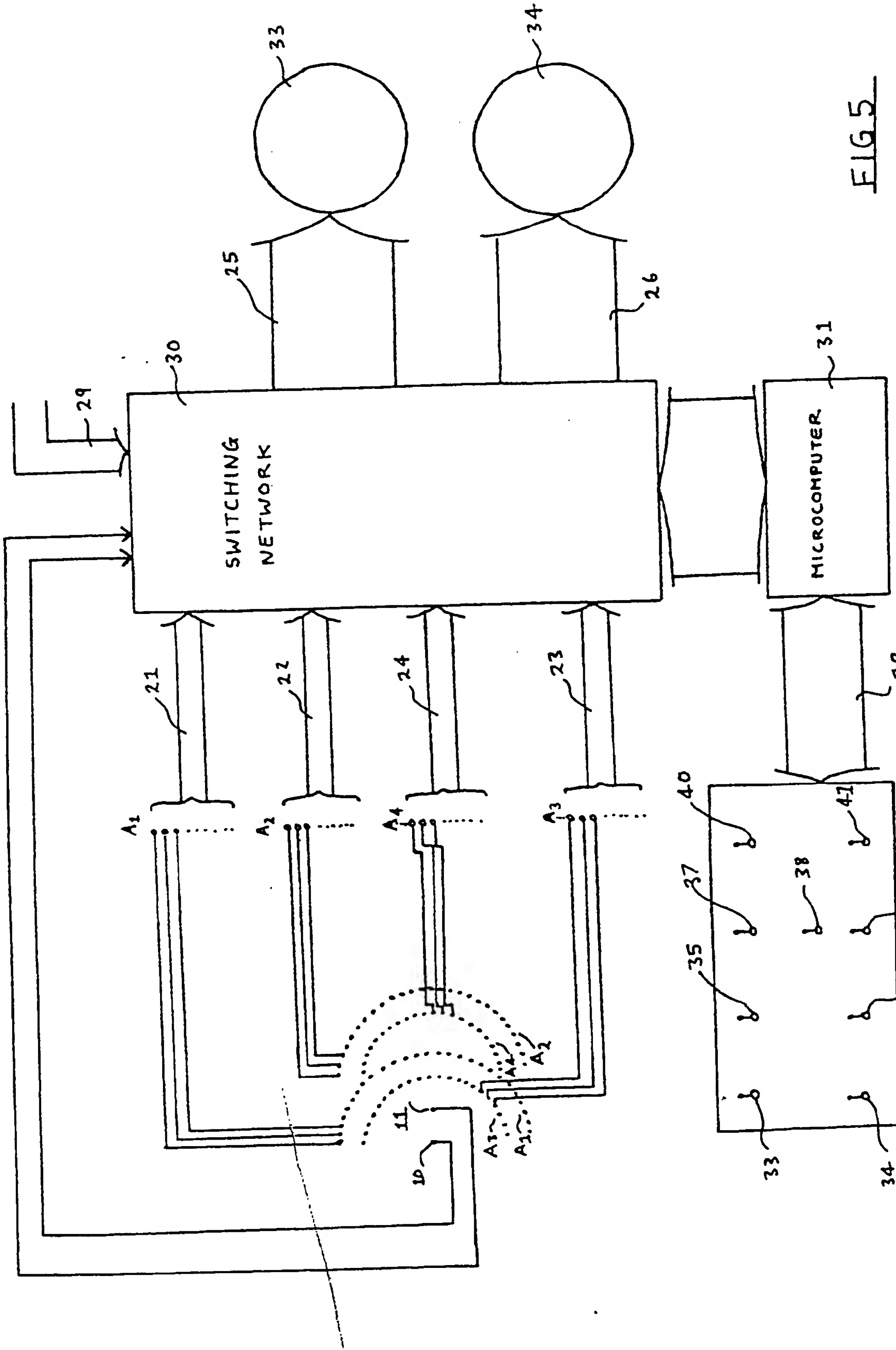


FIG.4


33
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SWITCHING NETWORK
MICROCOMPUTER
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23
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A_1
A_2
A_4
A_3
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FIG 5

SPECIFICATION

Method and apparatus for scanning an object field from a movable carrier

THIS INVENTION relates to a method and apparatus for scanning an object field from a movable carrier to provide measurements or images of the object field or parts thereof using curved scanning lines.

The scanning of objects, for example, the Earth's surface and/or clouds located thereabove is today predominantly carried out with straight or linear scanning lines running perpendicular to the direction of flight of the apparatus carrier, whether the objects are scanned to obtain measurement data or produce pictures or other graphic representations of the objects, and whether the images from which the measurements or representations are derived are formed in the visible light region, in the near infrared or in the thermal infrared, and likewise whether the apparatus is carried by aircraft or a satellite. By movement of the apparatus carrier, a gapless scanning of a stripe, for example, of the Earth's surface, can be accomplished by appropriate coordination of the speed of flight, flight altitude and opening angle of the optical system.

For a range of applications, particularly in the field of meteorology, scanning by straight lines has substantial disadvantages, for example, because the sighting angle, that is the angle between a given point of the object field and vertical, varies along a straight line in the object field. This can be avoided by scanning in circles or ellipses, as noted in ARCHIV Meteor. Geophys. Bioklimat Series B *21* 125–146(1973).

Formerly, in order to scan in curved lines, optomechanical systems have been required. The disadvantage of such systems lies particularly in that the mechanically moved parts, such as rotating or swinging mirrors create a substantial risk of failure, particularly when flown in space. If the scanning lines are to be in the form of two or more concentric circles, additional rotating and swinging devices, likewise subject to risk of failure, are necessary for optomechanically scanning. Furthermore, using such optomechanical systems, it is not possible to determine all measuring points on a scanning curve at once, and only sequential measurements along a curve are possible. This is a substantial disadvantage if the velocity of the apparatus carrier is not negligable compared to the scanning speed.

It is an object of this invention to provide a method and apparatus for scanning an object field using curved scanning lines without the necessity of mechanically moving parts, such as rotary or oscillating mirrors.

According to one aspect of the invention, there is provided apparatus for scanning an object field comprising an optical system having at least one objective lens for providing an image of the objectfield or a part thereof and an array of photo-sensitive detectors disposed in the image plane of the objective lens in at least one curved line for detecting at least part of the image, the apparatus being movable in a direction parallel to the image plane of the objective lens.

According to another aspect of the invention, there is provided a method of scanning an object field comprising forming an image of the object field or a part thereof by means of an optical system having at least one objective lens providing an array of photosensitive detectors disposed in the image plane in at least one curved line to detect at least part of the image and moving apparatus comprising the optical system and photosensitive detectors in a direction parallel to the image plane.

Thus apparatus and a method embodying the invention provide the capability of simultaneously determining all measurements or values on a scanning curve.

Preferably, the detectors are arranged in a full circle or in a circular arc, such as a semicircle, or in two or more circles or circular arcs, either concentric or offset from each other in the direction in which the apparatus is movable and it may be useful to provide a further additional detector on the optic axis of the optical system, particularly when the optic axis is vertical.

A substantial advantage of apparatus and a method embodying the invention is that using the curved detector arrays, scanning line shapes can be obtained that are realizable with difficulty or not at all in the case of optomechanical scanning. Preferably, where the scanning curves are full circles, the centre of curvature of the curves is arranged to be on the optical axis of the objective lens of the optical system, in which case the corrections for all points of the circle necessary for measurement are constant because of the natural vignetting of the objective lens. Also the imaging ratios may be given flexibility by the possibility of providing interchangable objectives. Thus, for example, it is possible to utilize so-called fish-eye objectives and thus to obtain sighting angles of up to 90° and greater thus allowing, for example, horizon scanning.

Pictures and graphical representations that can be evaluated stereoscopically may be provided with curvilinearly scanned convergent exposures using suitable mutually offset detector arrangements, for example the detectors may be arranged in arcs of circles or full circles offset in the direction in which the apparatus is movable. For investigation of radiation, it is less important to produce images or graphical representations than to obtain the most precise measurement values

thus scanning operations can be performed in such cases with relatively small optical resolution.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a schematic view of apparatus embodying the invention;

Figure 2 is a diagrammatic view of the image plane of Fig. 1, showing the circle on which the detector array is diposed;

Figure 3 is a schematic plan view of the image plane of apparatus embodying the invention illustrating an alternative arrangement of the detector array wherein the detectors are disposed on three concentric circles and an additional detector is provided at the centre of the circles;

Figure 4 is a schematic plan view of the image plane of apparatus embodying the invention illustrating a further alternative arrangement of the detector array wherein the detectors are disposed on two circles of the same diameter the centres of which are mutually offset by a distance *a* in the direction of flight; and

Figure 5 is a schematic block diagram illustrating an arrangement for switching and recording outputs from the detector.

Fig. 1 illustrates schematically apparatus embodying the invention comprising a camera having an objective lens O arranged to produce an image on a plane IP and a detector array arranged in the form of a circle in the image plane IP as is shown schematically in Fig. 2. The detector array may comprise a multiplicity of discrete detectors of a known type; for example, semi-conductor photo-detectors may be used. As shown in Fig. 1, an image of an annular area of the object field below the apparatus, for example the features of a landscape or a cloudscape, is produced at the circular detector array. Thus, as shown, an object section G produces an image at an individual detector element E.

The apparatus shown in Fig. 1 is carried by a carrier, for example an aircraft, satellite, or the like such that on forward movement of the carrier in the direction R, indicated in Fig. 1, a landscape strip of width ST may be fully scanned twice, first by the foremost semi-circle and then by the rearmost semi-circle of detectors shown in Fig. 1. The width ST of the strip which may be fully scanned is determined by the focal length of the objective lens and the radius of the circular detector array, while the resolution of the apparatus depends also on the size of the individual detectors and on the flight speed as well as the response time of the circuits to which the detector outputs are furnished. If only single scanning rather than a double scan is required, the detector array can be limited to the foremost or rearmost semi-circle only.

By use of a fish-eye objective lens, which provides an image wherein the spacing of image elements or points from the optic axis in the image plane of the lens is substantially proportional to the angle between the optic axis of the lens and the corresponding location at the object field, it is possible to obtain sighting angles of up to and more than 90° thereby enabling an image to be produced of an objectfield subtending an angle of up to and more than 180° at the objective lens and thus allowing even horizon scanning to be performed.

Fig. 3 shows, in plan view looking down on the image plane, an alternative arrangement of a detector array wherein the detectors are arranged on three concentric circles and an additional individual detector is provided at the common centre of the circles which may be arranged to coincide with the axis of the objective lens. These detectors can be simultaneously, or alternately, or otherwise selectively utilized for recording of images or measured values of the object field by switching means interposed between the detector arrays and recording means shown schematically in Fig. 5. Such detector arrays are particularly useful for investigation of the distribution and incidence of radiation, that is the radiation balance from outer space, in which case it is less important to produce images than to obtain mesured values that are as precise as possible. In such cases, consequently, it is possible to work with relatively low optical resolution. Further, using concentric circles of detectors allows the sighting angle to be selected.

Fig. 4 illustrates a further arrangement of the detector array for producing stereoscopic pictures or representations with the use of a single objective lens. The detector array comprises detectors arranged in two overlapping circles of the same radius. The centres of the two circles of detectors are mutually offset by a distance *a* in the direction of movement of the apparatus carrier providing a stereoscopic base of length *b* in the object field (not shown) which is related to the spacing *a* in the same way as the image dimensions are related to the object field dimensions.

As the apparatus carrier moves in the direction R, each point in the object field within the object strip ST is scanned twice by each circle of detectors: once by the foremost semicircle of detectors of each circle of detectors and once by the rearmost semicircle of detectors of each circle of the detectors, the scans by corresponding parts of the two circles of detectors being offset by the length *b* of the stereoscopic base. If only two scans rather than four are required the detectors may be arranged in semicircles corresponding to the foremost or rearmost semicircles of the two circles of detectors shown in Fig. 4.

The spacing *a* can be either firmly fixed or mechanically variable, the latter arrangement

being particularly to be considered if the detector array is arranged in part circles for example semicircles, rather than complete circles.

The optic axis of the objective lens 0 may pass through the centre of one of the two circles of detectors in the case of Fig. 4 or through the mid-point of the line connecting the centres of the two circles.

The features of the detector arrays of Figs. 3 and 4 (or parts thereof) may also be combined and again all or a part of the detector array can selectively be switched into and out of use, as generally illustrated in Fig. 5.

Fig. 5 shows schematically a switching system for selectively or collectively recording the outputs of the various sets of detectors. It is to be understood that pre-amplifiers, driving amplifiers, recording heads and so on would be provided in such a system, but these do not need to be shown as the use of such elements in the illustrated system is conventional and an attempt to show these elements would obscure the illustration of the switching facility.

As shown in Fig. 5, the detector array comprises four semicircular arrays of detectors A_1, A_2, A_3, A_4 arranged in a manner corresponding to a combination of the arrangement of Figs. 3 and 4, with dots representing individual detectors arrayed on the respective semicircles. Thus, the semicircular array A_1 is concentric with the array A_3, while the semicircular array A_2 is concentric with the array A_4, the centres of the two sets of concentric arrays being offset in the manner shown in Fig. 4. A central detector 10 is provided at the common centre of curvature of the arrays A_3 and A_1, while a central detector 11 is provided at the mid-point between the detector 10 and the common centre of curvature (not shown) of the semi-circular arrays A_2 and A_4.

A switching network 30, suitable for interconnecting multichannel data circuits in groups under the control of a microcomputer 31 is provided for connecting the detector arrays to one or both of two recording devices 33 and 34 which may be for example disc, drum or tape recording devices. The inputs to the switching network 30 comprise multichannel inputs 21, 22, 23 and 24 from detector arrays A_1, A_2, A_3 and A_4 respectively, an input from each of the detectors 10 and 11 and a flight information multichannel input 29 for flight velocity information, altitude information or the like that may need to be recorded on one or both of the devices 33 and 34 for proper future evaluation of the recorded information.

Multichannel outputs 25 and 26 from the switching network supply input signals to recording devices 33 and 34 respectively.

The microcomputer 31 is connected by a multichannel link 28 to a control panel 32. The switching system is turned on or off by means of a panel "PWR" switch 33 on the control panel. Similarly, all the detectors may be connected to or disconnected from the switch network 30 via an "ALL DET" switch 34. When only certain of the detectors are connected to the switching network via the switch controls to be described below, switch 34 may of course be used to disconnect those detectors.

A "STEREO-1, 2" switch 35 is provided to connect the outputs of arrays A_1 and A_2 via the switching network 30 to the recording devices 33 and 34 respectively while a similar "STEREO-3, 4" switch 36 will connect the outputs of arrays $A_3$and A_4 to recording devices 33 and 34 respectively.

Switches 37, 38 and 39 are provided to enable the arrays A_1, A_1 and A_3 respectively to be connected to the recording device 33 via the switching network 30. Switches 37, 38 and 39 may be designated switch a_1, switch $a_{1,2}$ and switch a_2 respectively where a_1 and a_2 refer to the sighting angles of arrays A_1 and A_3 respectively.

A "CTR 1,3" switch 40 allows the detector 10 to be connected to one of the channels of the multichannel output 25 while a "ST CTR" switch 41 enables connection of the detector 11 to a channel of each of the multichannel outputs 25 and 26 to provide input signals from the detector 11 to both recording devices.

CLAIMS:

1. Apparatus for scanning an object field comprising an optical system having at least one objective lens for providing an image of the object field or a part thereof and an array of photo-sensitive detectors disposed in the image plane of the objective lens in at least one curved line for detecting at least part of the image, the apparatus being movable in a direction parallel to the image plane of the objective lens.

2. Apparatus according to claim 1, wherein the photo-sensitive detector array comprises detectors disposed in a plurality of curved lines in the image plane.

3. Apparatus according to claim 1 or 2, wherein the or each curved line is an arc of a circle.

4. Apparatus according to claim 1 or 2, wherein the or each curved line is in the form of a circle.

5. Apparatus according to claim 4, wherein the detectors are arranged in a plurality of concentric circles.

6. Apparatus according to claim 5, wherein the common centre of curvature of the concentric circles is arranged to be the optic axis.

7. Apparatus according to claim 3 or 4, wherein the centres of curvature of respective lines of detectors are offset from one another

in the direction in which the apparatus is movable.

8. Apparatus according to claim 7, wherein means are provided for varying the distance between the centres of curvature or respective curved lines of detectors.

9. Apparatus according to any preceding claim, wherein a further additional detector is disposed on the optic axis in the image plane.

10. Apparatus according to any preceding claim, wherein means are provided for recording the output signals of the detectors.

11. Apparatus according to any preceding claim, wherein means are provided for switching all or a group of the detectors on or off simultaneously

12. Apparatus according to any preceding claim, wherein the optical system is arranged such that the spacing from optic axis of a given point in the image produced in the image plane is substantially proportional to the angle between the optic axis and the point in the object field producing the given image point.

13. Apparatus according to claim 12, wherein the objective lens is a fish-eye objective lens to allow sighting angles of up to and greater than 90° to be obtained.

14. A method of scanning an object field comprising forming an image of the object field or a part thereof by means of an optical system having at least one objective lens, providing an array of photo-sensitive detectors disposed in the image plane in at least one curved line to detect at least part of the image and moving apparatus comprising the optical system and photo-sensitive detectors in a direction parallel to the image plane.

15. A method according to claim 14, wherein the detector array comprises photo-sensitive detectors disposed in a plurality of curved lines in the image plane.

16. A method according to claim 14 or 15, wherein the or each curved line is an arc of a circle.

17. A method according to claim 14 or 15, wherein the or each curved line is in the form of a circle.

18. A method according to claim 17, wherein the detectors are arranged in a plurality of concentric circles.

19. A method according to claim 18, wherein the common centre of curvature of the concentric circles of detectors is arranged to be the optic axis of the optical system.

20. A method according to claim 16 or 17, wherein the centres of curvature of respective curved lines of detectors are offset from one another in the direction of movement of the apparatus.

21. A method according to claim 20, wherein means are provided for varying the distance between the centres of the respective curved lines.

22. A method according to any one of claims 14 to 21, wherein a further additional detector is disposed on the optic axis in the image plane.

23. A method according to any one of claims 14 to 22, and further comprising recording the output signals of the detectors.

24. A method according to any one of claims 14 to 23, wherein means are provided for switching all or a group of the detectors on or off simultaneously.

25. Apparatus for scanning an object field substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

26. A method of scanning an object field substantially as hereinbefore described with reference to the accompanying drawings.

27. Any novel feature or combination of features herein described.

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